MENTAL REPRESENTATIONS IN PHYSICAL EDUCATION

Significance of perceptional-cognitive action structures of teachers and learners in education

Linda Hennig

teachers
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physical education
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gymnastics

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MENTAL REPRESENTATIONS IN PHYSICAL EDUCATION

Significance of perceptional-cognitive action structures of teachers and learners in education

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GENERAL COMMENT

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CHAPTER 2 corresponds
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CHAPTER 3 corresponds
Hennig, L., Ghesneh, M., Mack, M., & Heinen, T. (2017). Development of individual instructions based on pupils' mental representations of a gymnastics skill. *Journal of Physical Education and Sport, 17*(4), 2604-2611.

CHAPTER 4 corresponds
Hennig, L. (2017). Mental representations in physical education students' evaluation of gymnastics skills. *Science of Gymnastics Journal, 9*(3), 265-277.

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SUMMARY

According to the *cognitive action architecture approach* (CAA-A; Schack, 2002, 2004), mental representations play a central role in movement control, as they are hierarchically structured in long-term memory and differentiate due to expertise. By means of *structural dimensional analysis - motoric* (SDA-M; Schack, 2012), movements are subdivided into *basic action concepts* (BACs) that are related to each other, to make mental representation structures visible. The method seeks to psychometrically depict the structural dimensions of conceptually ordered motor knowledge, both case-by-case and group-specific, and has been applied to a variety of sports contexts (Land, Volchenkov, Bläsing, & Schack, 2013). Although the examination of mental representations seems promising regarding the gain of insights into the structure of movements, motor learning processes and the relation of cognitive and movement structures, research in the field of educational research has not been conducted so far. Therefore, the aim of this dissertation project is to address the main research question: What influence can the knowledge about mental representation structures of movements have in the context of physical education and the optimization processes of learning and teaching?

The research issue, research program and research questions are presented in the general introduction of this thesis (*chapter 1*). To answer the main research question, three different perspectives are introduced in the main part.

The first perspective focuses on the structure of motor skills and the methodological approach to acquiring the mental representation structures. The practical implementation of the SDA-M is discussed in a text-image comparison of questionnaire items (*chapter 2*). The study aimed at determining an appropriate item format for the use of the SDA-M in the context of physical education. In light of the findings, the use of text or combined items is recommended when applying the SDA-M to children or adolescents.

The second perspective focuses on knowledge about the mental representation structure of learners and their execution of the skill. Based on pupils' mental representation structure, specific instructions are developed that might contribute to the optimization of movement execution (*chapter 3*). Results revealed that specific instructions based on pupils' mental representation of a gymnastics skill have a positive impact on their mental representation structure and on their motor performance.

The third perspective focuses on knowledge about the mental representation structure of teachers, here represented by sports students, examining its relation with their evaluation of pupils' movements (*chapter 4*). Results indicate that more structured mental representations are linked with a more precise performance evaluation. Therefore, a relation between physical education students' mental representation structure and their evaluation of gymnastics skills can be assumed.

Conclusively, in the general discussion, the key findings are highlighted, limitations are discussed and an outlook concerning practical implications and further research is provided (*chapter 5*). In sum, according to the findings of this dissertation, the acquisition and analysis of the structure of mental representations might constitute an effective means of optimizing the quality of physical education and can be seen as important for improving physical education teacher training as well as motor learning processes in general.

ZUSAMMENFASSUNG

Laut des *Cognitive Action Architecture Approaches* (CAA-A; Schack, 2002, 2004) spielen mentale Repräsentationen eine zentrale Rolle bei der Bewegungssteuerung, da sie hierarchisch im Langzeitgedächtnis strukturiert sind und sich aufgrund von Expertise unterscheiden. Mittels *Strukturdimensionaler Analyse - Motorik* (SDA-M; Schack, 2012) werden Bewegungen in *Basic Action Concepts* gegliedert (BACs), die miteinander in Beziehung gesetzt werden, um mentale Repräsentationsstrukturen sichtbar zu machen. Die Methode versucht, die strukturdimensionalen Zusammenhänge konzeptuell geordneten Bewegungswissens sowohl einzelfallbezogen als auch gruppenspezifisch psychometrisch darzustellen und wurde bereits in einer Vielzahl von sportlichen Kontexten angewendet (Land, Volchenkov, Bläsing, & Schack, 2013). Obwohl die Untersuchung von mentalen Repräsentationen vielversprechend erscheint, um Einblicke in die Struktur von Bewegungen, in motorische Lernprozesse und in das Verhältnis von kognitiven Strukturen und Bewegungsstrukturen zu gewinnen, fehlen Untersuchungen auf dem Gebiet der Bildungsforschung. Ziel dieses Dissertationsprojekts ist es daher, die zentrale Frage zu beantworten, welchen Einfluss das Wissen über mentale Repräsentationsstrukturen von Bewegungen im Kontext von Schulsport bzw. den Optimierungsprozessen von Lehren und Lernen haben kann.

Der Forschungsgegenstand, das Forschungsprogramm und die Forschungsfragen werden in einer allgemeinen Einführung dieser Arbeit vorgestellt (*Kapitel 1*). Um die dem Projekt übergeordnete Fragestellung zu beantworten, werden im Hauptteil drei verschiedene Perspektiven vorgestellt.

Erstens, wird eine Perspektive präsentiert, die sich auf die Struktur der motorischen Fertigkeit und den methodischen Ansatz zur Erfassung mentaler Repräsentationsstrukturen konzentriert. Die praktische Umsetzung der SDA-M wird in einem Text-Bild-Vergleich von Fragebogenitems diskutiert (*Kapitel 2*). Ziel der Studie war es, ein geeignetes Itemformat für den Einsatz des SDA-M im Rahmen des Sportunterrichts zu ermitteln. Angesichts der Ergebnisse wird die Verwendung von Textitems oder kombinierten Text-Bild-Items empfohlen, wenn die SDA-M bei Kindern oder Jugendlichen angewendet werden soll.

Zweitens, wird eine Perspektive vorgestellt, die sich auf das Wissen über die mentale Repräsentationsstruktur der Lernenden und ihre Bewegungsausführung konzentriert.

Basierend auf der mentalen Repräsentationsstruktur von Schüler_innen werden spezifische Instruktionen entwickelt, die zu einer Optimierung der Bewegungsausführung beitragen könnten (*Kapitel 3*). Die Ergebnisse zeigen, dass spezifische Instruktionen, die auf mentalen Repräsentationen einer turnspezifischen Fertigkeit basieren, einen positiven Einfluss auf ihre mentale Repräsentationsstruktur sowie auf ihre motorische Leistung haben.

Drittens, wird eine Perspektive vorgestellt, die sich auf das Wissen über mentale Repräsentationsstrukturen von Lehrenden, repräsentiert durch Sportstudierende, konzentriert. Die Beziehung zwischen der mentalen Repräsentationsstruktur von Lehrenden und ihrer Bewertung von Schüler_innenbewegungen wird untersucht (*Kapitel 4*). Die Ergebnisse zeigen, dass strukturiertere mentale Repräsentationen mit einer präziseren Leistungsbewertung einhergehen. Daher kann ein Zusammenhang zwischen der mentalen Repräsentationsstruktur von Sportstudierenden und ihrer Bewertung von turnerischen Fertigkeiten angenommen werden.

Abschließend werden in der allgemeinen Diskussion die wichtigsten Ergebnisse herausgestellt, Limitationen diskutiert und ein Ausblick in Bezug auf die Anwendungspraxis und weitere Forschung gegeben (*Kapitel 5*). Um die Ergebnisse dieser Dissertation zusammenzufassen, kann gesagt werden, dass das Erfassen und Analysieren mentaler Repräsentationsstrukturen ein wirksames Mittel zur Optimierung der Qualität von Sportunterricht darstellen kann und als wichtig für die Verbesserung der Ausbildung von Sportlehrer_innen als auch für motorische Lernprozesse im Allgemeinen angesehen werden sollte.

GENERAL INTRODUCTION

1 GENERAL INTRODUCTION

1.1 Research Issue: Theoretical Background

In physical education (PE), teachers and pupils act in an institutionalized framework of teaching and learning. One can imagine the following situation: A PE teacher has to teach his pupils the gymnastics skill of the forward roll. During his studies, he learned basic gymnastics movements, performed them himself and learned about the methodological steps to teach them. In the planning of the PE lessons, he decides to implement a methodological series. This is why in the gym, among other learning opportunities, he sets up a downward ramp of gym mats to make the practice of the rolling motion easier than on a horizontal surface. He explains the sequence of the movement to his pupils and asks a talented pupil to demonstrate the skill. He instructs the pupils on how to perform the forward roll, watches them, and gives feedback. Some of the pupils seem able to put the instructions into action. Some have problems performing the forward roll. The teacher tries to give instructions to help everyone and asks if they have any questions, but the pupils who are struggling cannot make out why, or even put into words why, they cannot perform the movement properly. One pupil is scared and does not dare to try. She has never performed a forward roll and feels scrutinized by her classmates. During the course of the lesson, the teacher supports her and tries to take her fear away, while pupils who manage the roll quite well on their own receive less attention. The lesson passes quickly, and after further hours of instruction and practice, the teacher grades the pupils' performance of the forward roll.

Bräutigam (2014) describes the overall context of PE as an institutionalized educational practice field. The practice of PE is produced in the current actions of the actors. Described above is a situation in which three variables interact with each other: the teacher, the learners and the skill (see Figure 1). This contemplation is based on considerations by Hawkins (2002/1974), who spoke of a relational triangle of "I, thou, it" (p. 51). The triangular relationship in this example consists of the teaching–learning object, the gymnastics skill of the forward roll, and the actors (teacher and learners/pupils) who act in the system of PE.

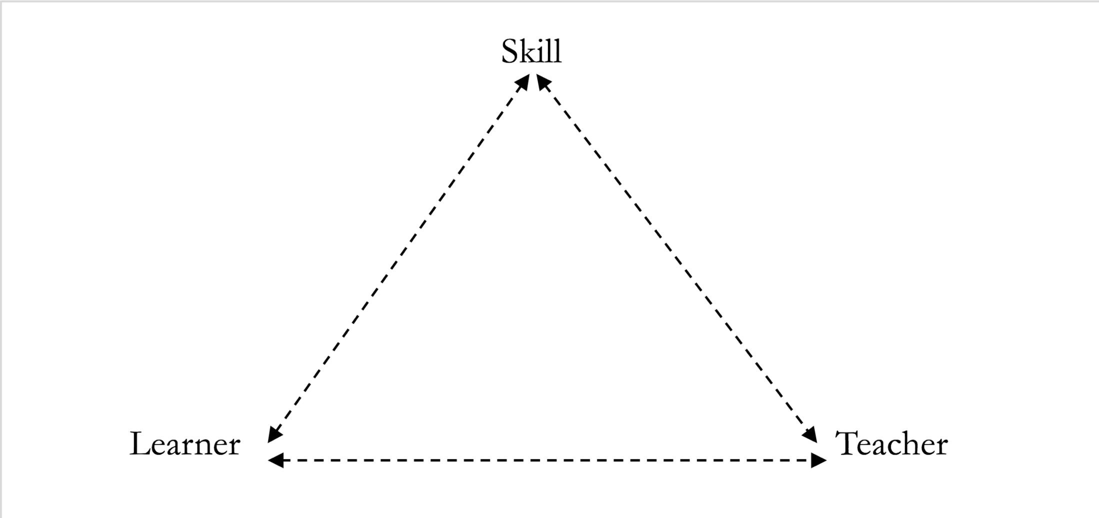

Figure 1. Relational triangle in the context of physical education (modified after Hawkins, 2002/1974).

Firstly, *the skill* is anchored in a curriculum and provides a certain structure, which distinguishes it from other contents. The forward roll, for example, requires a different methodical approach than a handstand or a jump throw in handball. In turn, this structure of the skill influences the other two variables (Arnold, Sandfuchs, & Wiechmann, 2009; Nitsch, 2004). Secondly, *the pupils* attend the PE lessons, learn the skill, and are likely to be required to give a technical presentation of the forward roll and be graded. They try to learn new movements in PE and come with different learning prerequisites and motivations. Have they performed a forward roll before? Have they observed the movement, giving them some idea of how it is performed? Their goal may be a good grade or the fun of the movement, but they may have no intention of learning the skill at all. They are confronted by the structure of the skill and have to deal with the teacher's instructions and considerations regarding how to learn the skill (Bräutigam, 2014). Thirdly, *the teacher*'s task is the movement mediation. He has an influence on pupils' performance gains. He plans and organizes the PE lesson, and performs and evaluates it. Different considerations regarding, for example, the aims, methods and organization of teaching come together in the planning. First of all, a curriculum specifies the content of his PE lessons. For example, it defines the aim: to enable pupils to perform a skill according to a technical guideline. Then, the teacher has to consider the teaching–learning object: the skill itself. What is the structure of the skill, and what is required to learn it? Furthermore, the teacher has to reflect on the method of how to get the pupils to achieve their goal as efficiently as possible. During the lesson itself, further considerations and decisions have to be made. How does the teacher split his teaching time between individual pupils and the class as a whole? Which instructions does he give? There is a need to consider the individual differences of the pupils. Additionally, the teacher has prerequisites that influence the situation – for example, whether or not the teacher himself can perform the movement (Dubs, 2009; Hasselhorn & Gold, 2017; Peterßen, 2000).

PE quality has many different aspects. Egger (2002) describes the conciseness and clarity of the goal formulation and the degree of individualization and differentiation of the goals as quality characteristics of teaching. Thus, the degree of individualization and differentiation that teachers can provide for their pupils might be enhanced by the ability to provide individual instructions. Furthermore, PE teachers must have different competencies in order to be able to work professionally. In addition to self-competence, social competences, and school competences, they need expertise in order to recognize the requirements of the teaching–learning object, including suitable selection, preparation, and presentation of the teaching content. In PE, teachers try to teach techniques of different sports to pupils within a relatively short time frame. With the appropriate method and various tools, they try to illustrate a technique for as many learners as possible (Bräutigam, 2014). In particular, the process of giving feedback and instruction, as well as the grading of pupils, requires PE teachers to have the competency of skill analysis (Nicaise et al., 2006). Research on teacher effectiveness (e.g., Lounsbery & Coker, 2008; Koka & Hein, 2003; Ryan, 2014) clearly shows that teachers' analytical competence and the quality of their feedback are decisive for successful teaching and learning in PE. For example, it has been suggested that teachers should create a stimulating learning environment by providing positive general feedback in motor learning situations, as studies on PE teaching have demonstrated that feedback is positively related to pupils' learning outcomes and to the differences regarding teacher effectiveness (Cloes, Hilbert, & Piéron, 1995; Cloes, Premuzak, & Piéron, 1995; Koka & Hein, 2003; Ryan, 2014). Furthermore, Lounsbery and Coker (2008) have shown a positive relation between motor skill level and participation in sports. Preparing and empowering pupils for lifetime physical activity is the goal of PE (Nicaise et al., 2006; Wolters, Ehni, Kretschmer, Scherler, & Weichert, 2000). Regarding the grading of pupils, Matanin and Tannehill (1994) showed that, next to active participation and knowledge, skill performance was regarded as the third most important factor by teachers for determining pupils' grades. Additionally, most European curricula contain aspects of motor skills, fitness, and health education, as well as the development of life skills (Liukkonen, Vanden Auweele, Vereijken, Alfermann, & Theodorakis, 2007; Volkamer, 1978). Thus, for example, the K-12 National Standards for Physical Education emphasize the importance of motor performance by stating that pupils should demonstrate competency in motor skills (Lounsbery & Coker, 2008).

How interesting and helpful it would be, therefore, to be able to "look inside the heads" of the actors in the above-mentioned situation and have a clear picture of the cognitive structures involved in the process of motor learning. This thesis will try to examine teachers' and learners' mental representation structures and question the role played by movement knowledge in this relationship of skill, pupil, and teacher (see section 1.2). In doing so, insights from sports science and motor learning (cognition and action, cognitive psychology, action representation) will be transferred to a new field of application: physical education. Thus, this work can be positioned in the field of PE research, where findings of sports education, sports psychology, and movement science can be brought together (Balz, Miethling, & Wolters, 2013). Within school performance studies, the demand has arisen for evidence of the effectiveness of PE lessons. Over the past few years, quality assurance in PE has been established based on learning outcomes (Stibbe, 2014). A paradigm shift in the education system from input to output control demands the visualization of the results of the lessons and looks for optimization possibilities. Sports science endeavored to establish a quality-oriented assurance for PE and to answer the question of which learning outcomes should be achieved in PE (Bundesministerium für Bildung und Forschung, 2007; Leyener, Bähr, Titlbach, Sygusch, & Gerlach, 2013; Trautwein, 2009). The field of PE research is considered as having potential for development, and research on motor learning of movement skills is still rare. An illustration of learning outcomes and development processes of the pupils would be desirable and could give an idea of the output of the lessons (Gerlach, 2009). This thesis addresses this issue by providing the possibility of visualizing pupils' and teachers' mental representation structures of motor skills.

In models of human memory, it is assumed that mental representations structure, store, and retrieve memory content (Eysenck & Keane, 2015). In the most general sense, representations represent an internal image of a stimulus a person encounters in the environment that is built up in memory (Paivio, 1986). This means that a stimulus in the human memory system is translated into an appropriate form (Anderson, 2013; Niederkofler & Amesberger, 2016). It is assumed that there are different modalities for different kinds of knowledge.

Following Anderson (2013) and Paivio (1986), a distinction can be made between perceptual and meaning-related representations. Perceptions can be represented, for example, visually and auditory, whereas meaning-related representations are conceptual and detached from perceptual-sensory experience. For the description of movement knowledge in motor action, amodal approaches seem to be appropriate (Engelkamp, 1990; Niederkofler & Amesberger, 2016). These approaches are explained by the fact that a cognitively represented image of the action as a visual representation is first transformed into an abstract representation of its meaning and then converted into a motor representation (Anderson, 2013; Niederkofler & Amesberger, 2016). This assumption goes back to scientific findings of cognitive research that point out how representations of sensory effects of movements play an essential role in action control (Bläsing, Tenenbaum, & Schack, 2009). The basis for intentional behavior is formed by the assumption that the excitation of an effect representation causes the execution of a movement. Effect representations are stored images of action effects in long-term memory and cannot be looked at independently of a person's movement apparatus. This means that they contain biomechanical information and are stored in the (motor) long-term memory (Schack, 2007, 2010). Motor science is based on an ideomotor conceptualization of motor control processes. In addition to the assumption that the effects generated in the environment are a consequence of the actual movement, it is also assumed that the movement is controlled by the intended and anticipated effects (Hossner, 2015). "Actions have been assumed to be cognitively represented by codes of relevant action features. [...] The only way to achieve this goal is to make the right move." (Hommel, 1996, p. 176). People act to produce an effect on the environment. The goal of our movement guides our action. Accordingly, the representation of the final state of our motor system is the guiding representation of our action (Schack, 2007). The coding of information in the form of action representations leads to memory content that corresponds to an emotional, cognitive and motor knowledge about motor actions. Mental representations of motor actions involve implicit, cognitive aspects of movement execution and, in contrast to knowledge representation, are not verbalizable. This has implications for interactions in learning situations (Niederkofler & Amesberger, 2016). If a learner knows how a forward roll works, but cannot adequately perform it despite this knowledge, it becomes clear that motor and knowledge representations have different qualities (Munzert & Hossner, 2008).

In order to examine the structure of mental representations of motor actions, Schack (2012) has developed the *structural dimensional analysis - motoric* (SDA-M)[1]. Using this method, a hierarchical structure of the representations is created in four steps. The movement sequence to be executed is decomposed into *basic action concepts* (BACs). In a paper–pencil test, participants must correlate the individual nodes of the movement with each other. From the correlated data, a tree diagram can be created using a mathematical algorithm, which represents the course of the movement as it is represented in the long-term memory of the participants (Schack, 2012). This experimental approach has been realized in several studies covering different fields of sports such as tennis (Schack & Mechsner, 2006), windsurfing (Schack & Hackfort, 2007), dance (Bläsing, Tenenbaum, & Schack, 2009), volleyball (Velentzas, Heinen, Tenenbaum, & Schack, 2010), judo (Weigelt, Ahlmeyer, Lex, & Schack, 2011), soccer (Lex, Essig, Knoblauch, & Schack, 2015), and golf (Frank, Land, & Schack, 2016), as well as different fields of application such as motor learning (Frank, 2014), technical preparation (Schack & Bar-Eli, 2007), cognitive training (Heinen, Schwaiger, & Schack, 2002; Kim, Frank, & Schack, 2017), and team sports tactics (Frank, Linstromberg, Hennig, Heinen, & Schack, 2018). In addition, in the field of gymnastics, some studies have worked with the recording of athletes' mental representations (Heinen, 2005; Heinen, Schwaiger, & Schack, 2002; Schack, 2003; Schack & Heinen, 2000; Simonsmeier, Frank, Gubelmann, & Schneider, 2018). Additionally, studies using the SDA-M on special groups of participants such as stroke patients (Braun et al., 2007), and most recently on athletes with a prosthesis (Jeraj, Musculus, & Lobinger, 2017) (chapter 2 add more information on the theoretical background, the methodological approach (SDA-M), and the state of research).

1.2 Research Program: Coherence of Work

Several studies have been conducted to examine athletes' mental representation structure (e.g., Schack & Mechsner, 2006), showing that knowledge about cognitive structures can lead to a better understanding of the motor learning process. However, PE remains open as a new field of application. In this thesis, motor actions characterized by the special context of

[1] In the literature, several full terms for the abbreviation SDA-M are proposed. In this thesis, the term *structural dimensional analysis – motoric* (Schack & Mechsner, 2006) is used consistently, referring to the method of acquiring subjects' mental representation structure.

PE are examined from a cognitive science perspective. PE is especially interesting: first, pupils are young novices and there is a wide range of performance levels, whereas most studies have examined adult novices or high-performance athletes; and second, teachers have to cover many areas of expertise, unlike coaches who tend to specialize in one sports domain.

The main research question is: What influence can the knowledge about mental representation structures have in the context of physical education and the optimization processes of learning and teaching? (see Figure 2).

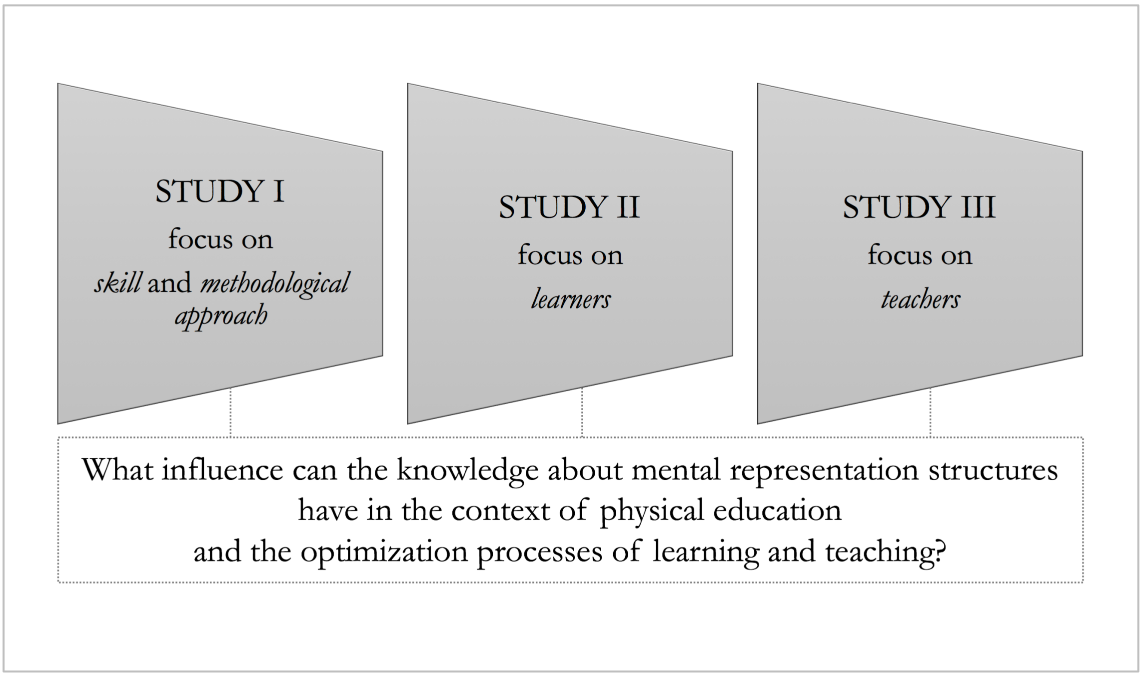

Figure 2. Overview of research program and main research question of this thesis.

Starting from the relational triangle in the constitutional framework of PE outlined in Figure 1, the first study of this thesis initially deals with the teaching–learning object: the skill and methodological approach used to assess the mental representation structure of the participants. In study I (chapter 2), to this end, the gymnastics skills of the cartwheel and forward roll are examined. They have been selected as examples of differently complex, discrete skills of an individual sport (gymnastics) and in accordance with the German curriculum for PE. On a list of frequency of taught sports, gymnastics is fourth with 61.3% (behind little games[2], basketball, and volleyball) (Gerlach, 2009). Beginning with

[2] 'Little games' referring to the German term 'Kleine Spiele'.

considerations on how the structure of the skill, accompanied by the mental representation structure of the skill, might look, current perspectives on action organization, as perceptual-cognitive approaches, and more particularly the *cognitive action architecture approach* (Schack, 2004a, 2010; Schack & Bar-Eli, 2007), are discussed in study I. In this context, *basic action concepts* are defined and the different levels that constitute the architecture model are specified. There are various possible approaches to the measurement of mental representations – for example, the determination of response behavior or the reaction time are discussed, and in the conclusion, the *structural dimensional analysis – motoric* is introduced as a possibility to assess mental representations. Furthermore, the practical implementation of the SDA-M in a text-image comparison of questionnaires is discussed, since the use of the items in previous studies differs (Bläsing et al., 2009; Land, Volchenkov, Bläsing, & Schack, 2013). Thus, it is necessary to determine which item format is appropriate for the application of the method for pupils to gain the best possible insights into their mental representations. The mental representation structure of gymnastic experts is assessed to generate an ideal structure for both movements. An item comparison is intended to shed light on which format is suitable for using the SDA-M method to elevate pupils' mental representation structure.

Returning to the relational triangle of teacher, pupil, and skill, the second study of this thesis deals with the learners. In study II (chapter 3), the results of study I are applied. If knowledge about the structuring of learners' mental representations of a motor skill is available, it is important to consider how this knowledge might contribute to an improvement of motor performance. Since one aim of PE is the acquisition of motor skills in the process of motor learning, and this process, in turn, is supported by teachers' instructions, these instructions might be a good starting point to enhance the process by using the mental representations as a basis of given instructions. The motor learning process can be divided into three phases. Firstly, the learner develops a coarse coordination of the movement, which improves during the second phase to become fine coordination and is ultimately stabilized in the third phase of learning in order to guarantee a variable availability of the movement (Brand, 2010; Meinel & Schnabel, 2007). By analyzing the representation structure of the movement, targeted instruction could facilitate the achievement of a higher execution level. Since each individual has an individual mental representation structure, it is of great interest to make these "images in the minds" visible. Based on pupils' mental representation structure, specific instructions are to be developed that contribute to the optimization of the movement. Memory structures make it possible to analyze movements that cannot be directly identified using other diagnostic methods, such as video. A sports-didactic concept is that of *educational* physical education[3], which pursues the guiding principle to educate, on the one hand, *about* sports, and on the other hand, *by doing* sports (Kurz, 2000). For example, pupils should learn and reflect about sporting processes, and their willingness to learn and perform should be encouraged by PE. An awareness of the pupils' own abilities contributes to the development of their identities and the strengthening of self-awareness (Bräutigam & Kamper, 2007). Approaches presented in this concept are supported by the approach in this thesis, since the goal comprises both the assessment of the individual learning level as well as an optimization of the motor performance of the pupils.

In line with the relational triangle in Figure 1, the third study of this thesis deals with the teacher. Study III (chapter 4) focuses on PE students[4], who represent teachers in this thesis. The mental representations of the skills in the teachers' long-term memory are the basis for their actions and their communication in sports lessons (Hommel, 1996). The planning and execution of the lesson are implemented on the basis of their representations. But as well as the guidance of the process of motor learning – for example, the acquisition of new sports skills like the forward roll – being influenced by teachers' mental representation structures, so are the observation, evaluation and grading of pupils' performance. Possible interrelations between PE students' mental representation structures and their evaluation of pupils' motor performance could provide important insights for teacher training and education. Hereby, starting points are developed for the optimization of teaching and learning processes in (sports) education.

1.3 Research Questions: Purpose of Work

Dealing with organizational structures of mental representations of movements, the purpose of this thesis is the acquisition of the mental representations of skills in the long-term memory of learners and teachers. In a split procedure, pupils, as well as PE students,

[3] '*Educational* physical education' referring to the German term 'Erziehender Sportunterricht'.

[4] In this thesis, the term 'students' is used to refer to undergraduates studying at university and the term 'pupils' is used to refer to school pupils.

should relate individual sub-steps of a movement. Thus, the mental movement representation stored in the long-term memories of the participants can be presented in the form of tree diagrams. The main research question of this doctoral thesis asks whether and how the recording of mental representation structures can be implemented in a school-based context, and how knowledge of these cognitive structures influences processes of teaching and learning. To answer this question, three different main perspectives are presented:

The first perspective focuses on the *skill and methodological approach*, asking how knowledge about mental representation structures can be assessed in pupils. Consequently, it was the aim of study I to determine the impact of different display formats (text vs. picture vs. combined items) on the results of the SDA-M and to figure out which display format best matches an *ideal* mental representation structure of an action in participants with an average age of 12 years.

It was hypothesized that regardless of the experimental groups (experts vs. novices) and the task (forward roll vs. cartwheel), the results of the SDA-M will have subtle distinctions depending on the item format. It was further assumed that the mental representation structure revealed by a questionnaire with text items differs from one with picture items, and that the comparison of picture items and combined items (picture vs. combined) and text items and combined items (text vs. combined) shows no significant difference. Considering the experimental groups (experts vs. novices), the individual results depending on the display format are expected to differ more in novices than in experts. Further, it was assumed that the novices differ more from the ideal structure than the experts.

The second perspective focuses on knowledge about the mental representation structure of *learners*, asking how knowledge about the structuring of the mental representations of learners can be useful in the context of PE. Consequently, the aim of study II was to analyze the impact of specific and general instructions on pupils' cognitive and motoric development.

It was hypothesized that both types of instructions (specific vs. general) would lead to functional changes in the mental representation structures, along with motor performance improvement. Furthermore, it was expected that specific instructions would be more effective than general instructions in the development of mental representation, since the specific instructions take into account the individual structuring of mental representations of each pupil. In addition, it was assumed that specific instructions would lead to better motor performance than general instructions.

The third perspective focuses on knowledge about the mental representation structure of *teachers*, asking how knowledge about the structuring of their mental representations influences evaluation processes in the context of PE. Consequently, the aim of study III was to analyze the relation between PE students' mental representation structure and their evaluation of pupils' skill performance.

It was hypothesized that an expert-like mental representation structure has a positive influence on PE students' evaluation of pupils' skill performance. The more similar the PE students' representation structure is to an expert reference structure, the more similar the performance evaluation of the motor skills should be to an expert rating. Regarding the two gymnastics skills of the cartwheel and the forward roll, it was assumed that there is a task-specific difference in difficulty. Performing the forward roll, a basic floor exercise in gymnastics, the athlete rotates about one axis of the body. Performing the cartwheel, a more complex floor exercise in gymnastics, the athlete rotates about every axis of the body (frontal axis rotation anterior, longitudinal axis rotation, transverse axis rotation, longitudinal axis rotation, frontal axis rotation posterior).

2 THE MEASUREMENT OF MENTAL REPRESENTATIONS WITHIN THE CONTEXT OF MOTOR ACTIONS

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Abstract

Relating to the *cognitive action architecture approach* mental representations figure prominently in motion control, since they are stored hierarchically structured in long-term memory and differentiate between novices and experts. Firstly, in this chapter, theoretical foundations in the field of cognitive psychology and movement science are sketched out to emphasize the significance of mental representations in understanding, explaining and enhancing motor actions. Secondly, various methods of quantifying mental representations will be revealed, focusing on a methodical procedure called *structural dimensional analysis - motoric* (SDA-M). Thirdly, the state of research and differences in realization of this method lead to the main question that will be addressed in this chapter. Since there has been varying display formats when assessing mental representations in the literature, the aim of the present study is to determine possible differences between display formats of the items used in the SDA-M in gymnastics. Results of the study will be discussed and relevant aspects for practical implementation will be added for consideration.

Keywords: measuring mental representations, basic action concepts, long-term memory, text-picture-comparison

3 DEVELOPMENT OF INDIVIDUAL INSTRUCTIONS BASED ON PUPILS' MENTAL REPRESENTATIONS OF A GYMNASTICS SKILLS

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Abstract

In physical education, teachers use instructions to support the learning of motor skills (Wulf, Höß, & Prinz, 1998). Expertise in performing motor skills is characterized by forming and adapting relevant mental representations that are stored hierarchically structured in long-term memory (Land, Volchenkov, Bläsing, & Schack, 2013; Schack & Mechsner, 2006). Scientific findings reveal differences between experts' and novices' mental representation structures in the comparison of different skill levels (Bläsing, Tenenbaum, & Schack, 2009), as a consequence a close relationship between mental representation structure and skill performance is presumed, and a development of mental representation structures over the course of learning could be highlighted (Frank, Land, & Schack, 2016). Therefore, the purpose of this study was to investigate the differences in the effects of two types of instructions (specific vs. general) on pupils' development of mental representation structures and their performance of a cartwheel. Sixteen pupils were assigned to one of two conditions: specific or general instructions on the performance of a gymnastics skill (cartwheel). Participants in the intervention group received specific instructions, based on their mental representation structure of the cartwheel, whereas participants in the control group received general instructions. Results revealed that specific instructions based on pupils' mental representation of a gymnastics skill have a positive impact on their mental representation structure as well as on their motor performance. It can be concluded that the knowledge about learners' structure of mental representations could constitute an effective means of developing specific instructions for enhancing motor performance.

Keywords: physical education, teachers, cartwheel, performance increase, SDA-M

4 MENTAL REPRESENTATIONS IN PHYSICAL EDUCATION STUDENTS' EVALUATION OF GYMNASTICS SKILLS

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Abstract

Research provides evidence that mental representations control human actions. It also shows a relation between mental representations and factors that might influence performance evaluation. The evaluation of motor skills figures prominently in physical education (PE) because it influences central tasks of teachers, like the provision of feedback and grading. Therefore, the purpose of this study was to examine the relation of PE students' mental representation structures and their evaluation of pupils' gymnastics skill performance. Mental representations and performance evaluations of the cartwheel and the forward roll were assessed in $N = 30$ PE students, by means of *structural dimensional analysis - motoric* and a video test. Participants' mental representations and performance evaluations were compared to an expert reference. Results revealed significant differences regarding the comparison of performance evaluations for a group of participants with more structured and a group with less structured mental representations, indicating that more structured mental representations are linked with a more precise performance evaluation. The study demonstrates that there is a relation between PE students' mental representation structure and their evaluation of gymnastics skills. Consequently, it is proposed to implement obligatory physical and mental training in the gymnastics training for future PE teachers, in order to develop expert-like mental representation structures and improve performance evaluation.

Keywords: performance evaluation, SDA-M, forward roll, cartwheel

GENERAL DISCUSSION

5 GENERAL DISCUSSION

5.1 Summary: Key Findings

The current thesis focused on the investigation of teachers' and learners' mental representation structures of gymnastics skills in the context of PE. The aim was to provide insights into the potential application of knowledge about the cognitive architecture of motor actions.

Study I aimed at determining an appropriate *item format* for the use of the SDA-M in the context of PE. In light of the findings, the use of text or combined items is recommended when applying the SDA-M to children or adolescents.

Study II aimed at examining the impact of specific *instructions* developed based on pupils' mental representation structure. Results indicate that specific instructions based on mental representation structures have a positive impact on pupils' skill representations in long-term memory as well as on their motor performance. It can be concluded that in motor learning, knowledge about the structure of mental representations is essential for teachers and learners. Teachers might benefit because it becomes possible to choose and give appropriate instructions. Learners' current performance level can be assessed, and specific instructions can be provided that help to improve their motor skills.

Study III aimed at examining the relationship between teachers' mental representation structure and their *evaluation* of pupils' performance of a skill. It can be concluded that a more structured mental representation leads to a more precise performance evaluation. Thus, PE students use their mental representations of a motor skill as a basis for the evaluation of skill performance.

When interpreting the results, there are limitations of the studies that should be kept in mind (see section 5.2). However, according to the findings of the present work, the acquisition and analysis of the structure of mental representations could constitute an effective means of optimizing the quality of PE and can be seen as an important tool for improving PE teacher training as well as motor learning situations in general.

5.2 Discussion: Limitations

The summary of the results shows that knowledge about mental representation structures seems to have a positive influence in the context of motor learning in PE. Nevertheless, there are limitations of the studies that must be considered and taken into account in the discussion of the results. There are, furthermore, questions related to this work that remain unanswered and should be addressed in further research.

In addition to the display format of items that was the focus in study I, the application of the SDA-M provides further points that might influence the results. Other display formats – for example, video sequences – could be considered as well. Taking into account study I showing different results for text and picture items or combined items, one might expect different results for video sequences as well, since they contain different (more) information compared to pictures or texts. Other issues that could be addressed in follow-up studies are the methods of application (procedure) – for example, paper-pencil test vs. computer-based test. Due to practicability in the gym, paper-pencil tests were used in the present work. Furthermore, the statistical evaluation in this thesis follows Jeraj (2016), who proposes an innovative approach by calculating single correlation coefficients to display differences in mental representation structures. Preliminary studies used the λ-value as a measure of invariance (Lander, 2002), and the Adjusted Rand Index as a measure of similarity (Rand, 1971) to explicate the meaning of the results.

Furthermore, two gymnastics skills were selected in this thesis to exemplify a more complex (cartwheel) and a more basic (forward roll) floor exercise in gymnastics and because of the defined evaluation criteria for gymnastics skills. Thus, the use of knowledge about mental representation structures is effective regarding discrete skills (e.g., the cartwheel in gymnastics) that can easily be subdivided into phases. Regarding continuous skills (e.g., swimming), studies show a successful application of the SDA-M (Engel, 2009). However, further research could focus on skills with different demands, such as skills performed in an unstable and dynamic environment and with or without object manipulation (Gentile, 1972). Task difficulty and task demands might have an influence on the mental representation structure. The impact of instructions or the evaluation and grading of a motor action could depend on the type of task.

Two considerations should be made with regard to the groups of participants. First, regarding study II, it would be interesting to have a mixed group of pupils, since most PE classes are not gender separated. It would be interesting in this context to investigate a possible interaction between gender and task. Across children and adolescents, gender differences have been reported in performance for many motor tasks (e.g., balance and catching), depending on age and task (Thomas & French, 1985). Maybe specific instructions that are developed on the basis of mental representation structures are effective for girls but not for boys, since biological and environmental influences have to be taken into account. Second, regarding study III, it would be important not only to investigate mental representation structures of students but also of, for example, teachers with teaching experience of several years or even several decades. Groups of participants with different teaching experience could be compared, and examination of the development of mental representations during a teacher's career could be an interesting point of focus.

Additionally, an important question that should be addressed in further research is the sustainability of the results. Changes of mental representation structures or motor performance over time should be examined in retention tests. Especially in the context of PE, it would be important to know whether the given instructions obtain results that persist, given that more than one learning object (e.g., learning how to perform a skill) has to be realized in a short time frame.

5.3 Conclusion: Research Prospects

To conclude and provide an outlook on practical implications and further research, we come back to the initial example of the teacher attempting to teach his pupils a forward roll in PE: To start the PE lesson with an initial diagnosis of the learning levels of the forward roll, the teacher could use a method to elevate the mental representation structures of his pupils. He could use his knowledge of methodological series acquired during his studies to develop exercises that help his pupils. Some pupils might not need the aid of a downward ramp, but they might need help with the placement of their hands instead. The knowledge about the pupil's mental representation structures could help the teacher to recognize this. In addition, an individualized instruction card would enable upward differentiation, which means that even the pupils who already have a good command of the movement will receive an instruction that will help them to improve. Each pupil would receive individual help, not just those corrected by the teacher. For the pupil afraid to perform the rolling movement, a

SDA-M questionnaire evaluation may give some indication of where in the movement the pupil has stored an incorrect representation, and it could be used to solve her blockade. In terms of the grading at the end of the lesson, the teacher knows that his mental representation structure influences the evaluation of the pupils' performance. The results of this thesis show that by means of methods that measure mental representation structures of motor actions (e.g., the SDA-M), it seems possible to "look inside the heads" of the actors in PE. The three studies conducted in this thesis provide a starting point for research examining the relational triangle of skill, learner, and teacher.

Firstly, all three studies show the importance of detailed analysis of the skill. The process of analyzing the BACs as described in study I seems to optimally map the structure of the movement. This method could possibly complement prototypical skill models. Including experts as well as novices in the process of generating the items seems sensible, since precisely tailored descriptions of the BACs can be determined. The involvement with the BACs could deepen learners' as well as teachers' own understanding of the skill. It could probably help teachers to think about the skill content from the pupils' perspective and help them to represent the skill in appropriate and engaging ways. Furthermore, in study I, the examination of the methodological approach (SDA-M) showed that different item formats of the BACs lead to variations in the representation of the stored mental structure of an action. The findings show that picture items and combined items provide a very similar result; for young subject groups, text items deviate most from an ideal structure, and thus it is suggested that pictures, or combined items, be used when applying the method to children or adolescents. The results show that it makes sense to adapt the item format to the group of participants and should sensitize to constantly check the quality of the measuring instrument.

Regarding the two chosen gymnastics skills of the cartwheel and the forward roll, study I and study III revealed differing results. It can be assumed that there is a task-related difference depending on the complexity of the skill in both studies. In study I, the results of the cartwheel show a larger difference between the comparison of text items with the ideal structure than for the forward roll. Corresponding to these findings, in study III, it seems to be easier for the PE students to evaluate the forward roll compared to the cartwheel. Different difficulty levels of motor skills might not only structure the mental representation but also affect the observer's performance evaluation. These results should be considered, since task difficulty influences teaching-learning situations.

Secondly, the particular strength of the approach seems to be the consideration of the individual requirements and needs of the learners. The benefits of this approach have been especially demonstrated in the field of high-performance sports. The results of study II now suggest that knowledge about structures also pays off in PE, since findings revealed that specific instructions based on pupils' mental representation of a gymnastics skill have a significant positive impact on their mental representation structure as well as on their motor performance. In particular, these results seem to be of high value for teaching practice.

Focusing on the group of participants chosen in this study, it is important to consider that instructions play an important role in PE. Learners have to be provided with the correct information and instructions regarding their motor performance to be able to enhance their skills. But in PE practice, the time frame for motor learning is limited. Often, one teacher has to provide instructions to groups of 25 or more pupils. Time constraints prevent detailed observation of each pupil. Therefore, it is not always possible to detect pupils' individual errors and needs. The knowledge about learners' structure of mental representations could help in choosing and providing the necessary instruction. If a teacher assesses the mental representation structures of his or her pupils, one major advantage would be the possibility to develop arrangements for differentiated instruction provision. It would be possible to give specific instructions to each pupil depending on his or her own needs, strengths and weaknesses, and the current performance level. The time required to capture pupils' mental representation structure is relatively short. Filling in the questionnaire takes just a few minutes, depending on the number of items. Creating the questionnaires and the evaluation is more time-consuming; however, there is a long-run payoff. Time can be saved by giving out the questionnaires, for example, as a homework assignment. In addition, further possibilities of using the questionnaire can be considered. Since the results of the questionnaires provide information about the pupils' current level of mental representation structure, it would be possible to use them as a kind of substitute for learning objective controls. The results of study II invite us to think about future possibilities. Thinking one step further, it might also be possible to create a kind of catalog with ready-made school questionnaires that teachers can use as a diagnostic tool in PE. It would also be conceivable to use tablets, which are already available in some schools. Pupils would be able to complete the questionnaire via an app, and the results would be displayed directly (for example, in the form of a tree diagram of each pupil for the teacher and an individualized instruction card for the pupils).

The results of study II are in line with the findings of Weigelt et al. (2011) showing that the SDA-M could be used as a diagnostic tool. Pupils' mental representation structures in a pretest were used as a basis for instructions that led to improved motor performance. What is interesting in this respect, however, is that it does seem possible to use knowledge about the structuring of mental representations, even among young, inexperienced learners. This might complement the findings of studies examining experienced athletes (e.g., Velentzas et al., 2010; Weigelt et al., 2011). On the other hand, Simonsmeier et al. (2018) show rather different outcomes, since their SDA-M results on changes in the mental representations were inconsistent. A possible explanation might be the different item format, because Simonsmeier et al. (2018) used text items in the SDA-M. Precisely for this reason, these results should encourage further studies to confirm and strengthen the results of this dissertation. Furthermore, the results of this thesis are in line with the findings of Frank et al. (2016) indicating that mental representation structures develop over the course of learning. Here, however, a very short practice time seems to lead to functional changes in pupils' mental representation structure. Results further complement findings of Velentzas et al. (2010) emphasizing a relationship between mental representation and performance. They examined the mental representation structures of overhand volleyball service routines and showed that the quality of athletes' mental representation structures correlated with the coach's performance ranking. The positive correlation between the mental representation and motor performance for the intervention group's posttest results in study II are an indication of a direct link between a well-structured mental representation and a skilled motor performance.

Thirdly, results of study III revealed a relation between the mental representation structure and performance evaluation of PE students. Data indicate that the more similar the PE students' mental representation structure of the gymnastics skill compared to an expert's mental representation structure, the more similar the performance evaluation of this skill compared to an expert's performance evaluation. This means that it might be possible to directly enhance teachers' performance evaluation by influencing and changing the mental representation structures in their long-term memory.

Although the demands and performance assessments in the school are different compared to competitive sports, pupils are nevertheless rated on the basis of guiding principles, and a differentiated assessment of the movements leads to a fair and justifiable grade. Therefore, consideration should be given to implementing obligatory physical and mental training in gymnastics training for future PE teachers.

Ensuring the quality of teaching in PE is fundamental, but it is affected by various factors. Sport is voluntary in free time, and there are manifold reasons for participating. Participation in PE is compulsory for the pupils. Performance is certainly present in PE, and is measured and graded (Kurz, 1975). At school, contents of the lessons are regulated by curricular specifications. Grades should serve information, selection, and motivation (Wolters et al., 2000). The learning time in school is limited. In a relatively short time, new skills should be learned. In addition, teachers often work with a class size of up to 30 children and do not have the time and capacity to care for and support each student individually. Using the SDA-M, the teacher could provide individual instructions for all students in a class, and also document their development by comparing the representational structures at the different test times (study II). A better mental representation structure could lead to a better performance evaluation and thus a more appropriate grading of the pupils (study III).

With regard to future research, it would be interesting to take a closer look at the relation between the mental representation structures of PE teachers and their pupils. An interesting question could be whether the development of learners' mental representations is influenced by their teacher's mental representation structure and whether one can draw conclusions on the methods of mediation on the basis of representative structures. This could help to provide insights into the communication between teachers and learners, as well as possible ensuing difficulties. Another consideration could be a comparison of teachers who have different expertise in a skill. Possible differences in the mental representation structure could allow more direct deductions and recommendations for the education of sports teachers. The question of whether teachers should be able to perform movements to convey them could be the focus in such a research area.

This thesis provides a starting point for further research projects in the field of educational research, since the application of the SDA-M method or the acquisition of mental representation structures is not limited to PE. The acquisition of knowledge structures is also conceivable in other subjects – for example, in mathematics – and thus the development or integration of the method as a standard tool for diagnostics in the classroom could be a possible goal. Teachers could use the collection of pupils' representation structures to diagnose how representations in students' long-term memory evolve based on their teaching. It would be desirable to create a lesson that achieves the optimal representation structure for the pupils as quickly as possible.

Thus, the acquisition and analysis of the structure of mental representations could be implemented in physical eduction or in other areas – such as popular sports – where inexperienced athletes can benefit from individual instructions. This approach can help to determine athletes current performance level, to provide appropriate instructions, to assess relations between cognitive structures and performance evaluation, and therefore, to improve motor learning situations, the interaction of teachers and learners, PE teacher training, and evaluation processes.

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